



US009053791B2

(12) **United States Patent**  
**Walsh et al.**

(10) **Patent No.:** **US 9,053,791 B2**  
(45) **Date of Patent:** **Jun. 9, 2015**

(54) **FLASH MEMORY WITH INTEGRATED ROM MEMORY CELLS**

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(\*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 280 days.

(21) Appl. No.: **13/665,461**

(22) Filed: **Oct. 31, 2012**

(65) **Prior Publication Data**

US 2013/0235672 A1 Sep. 12, 2013

**Related U.S. Application Data**

(60) Provisional application No. 61/608,006, filed on Mar. 7, 2012.

(51) **Int. Cl.**

**G11C 16/10** (2006.01)

**G11C 16/04** (2006.01)

**G11C 17/12** (2006.01)

(52) **U.S. Cl.**

CPC ..... **G11C 16/04** (2013.01); **G11C 17/12** (2013.01); **G11C 2216/26** (2013.01)

(58) **Field of Classification Search**

CPC ..... **G11C 16/10**; **G11C 16/12**

USPC ..... **365/185.11**, **185.18**, **230.03**, **63**

See application file for complete search history.

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*Primary Examiner* — Son Dinh

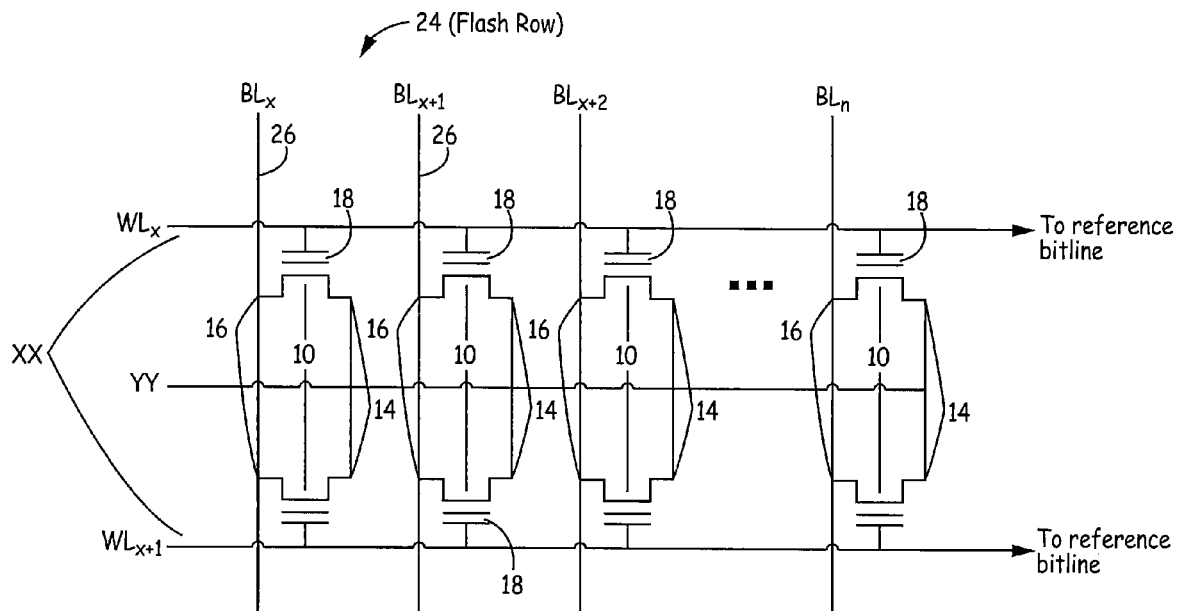
(74) *Attorney, Agent, or Firm* — Evans M. Mburu; Stephen W. Bauer

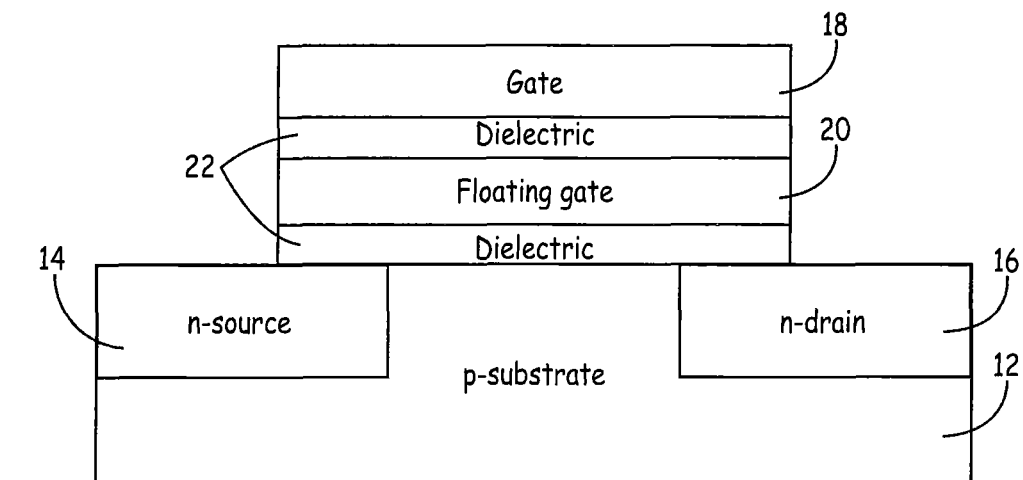
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**ABSTRACT**

Memory array for storing a plurality of data bits. The memory array has flash memory cells, ROM memory cells addressing circuitry. The addressing circuitry is operatively coupled to both the plurality of flash memory cells and the plurality of ROM memory cells, the addressing circuitry being configured to address both the plurality of flash memory cells and the plurality of ROM memory cells.

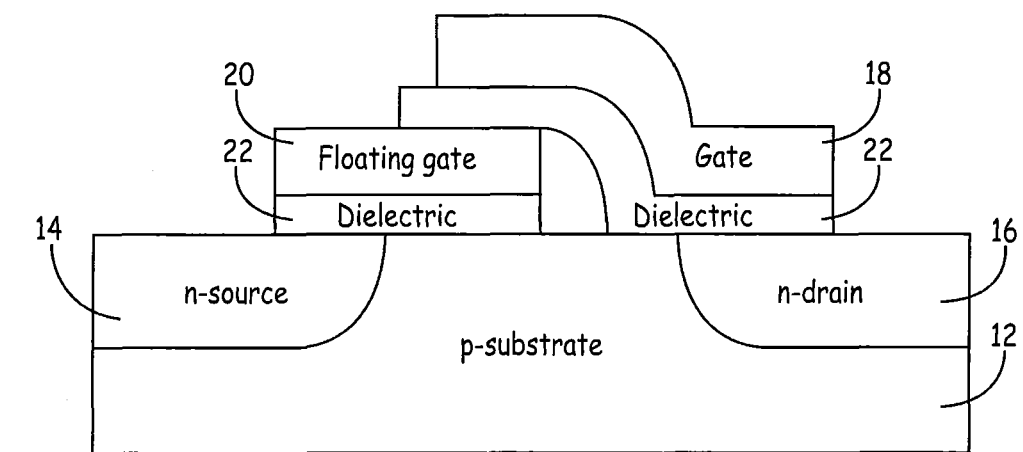
**9 Claims, 18 Drawing Sheets**





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**FIG. 1a**  
(PRIOR ART)



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**FIG. 1b**  
(PRIOR ART)

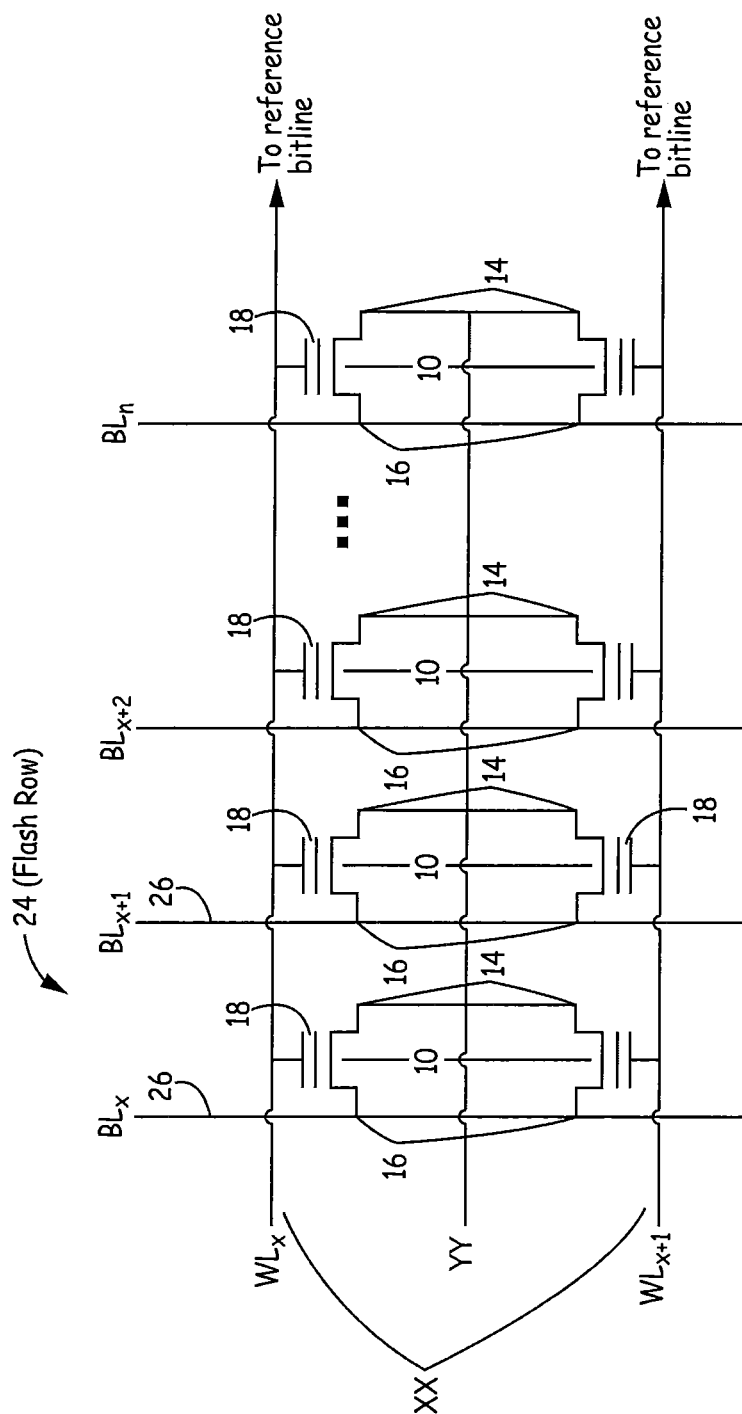
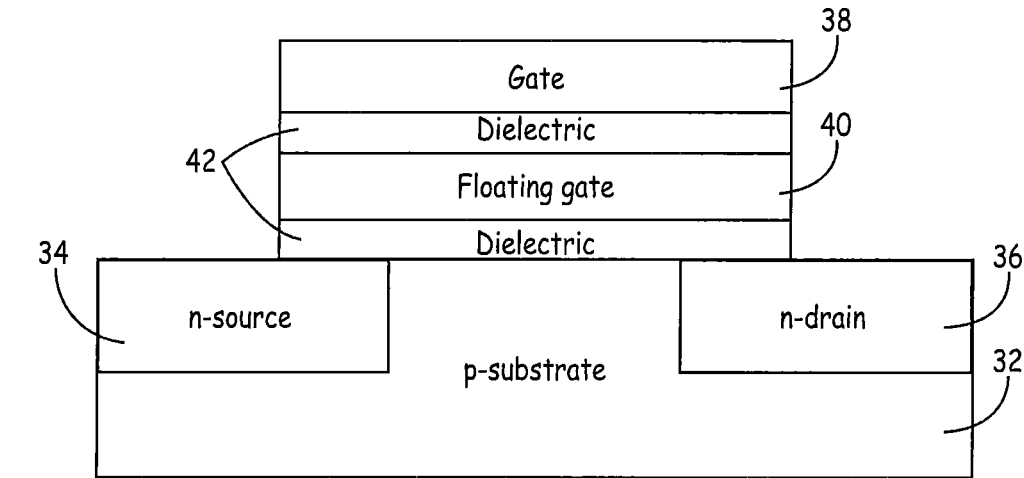
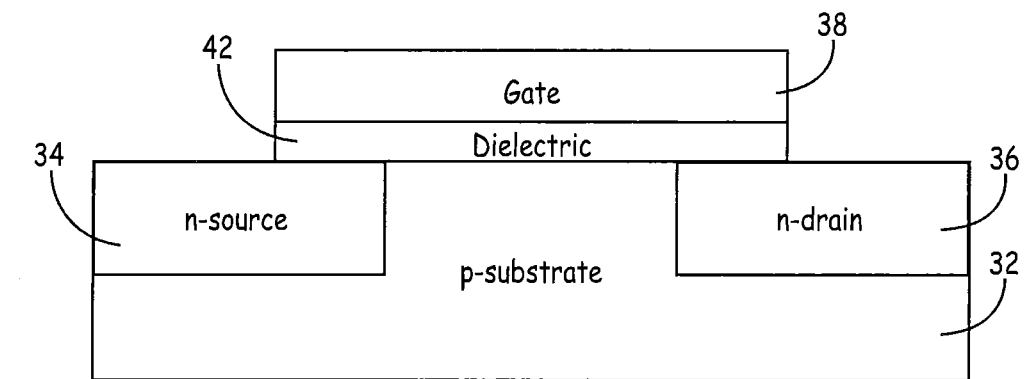


FIG. 2



30

FIG. 3a  
(PRIOR ART)



30

FIG. 3b  
(PRIOR ART)

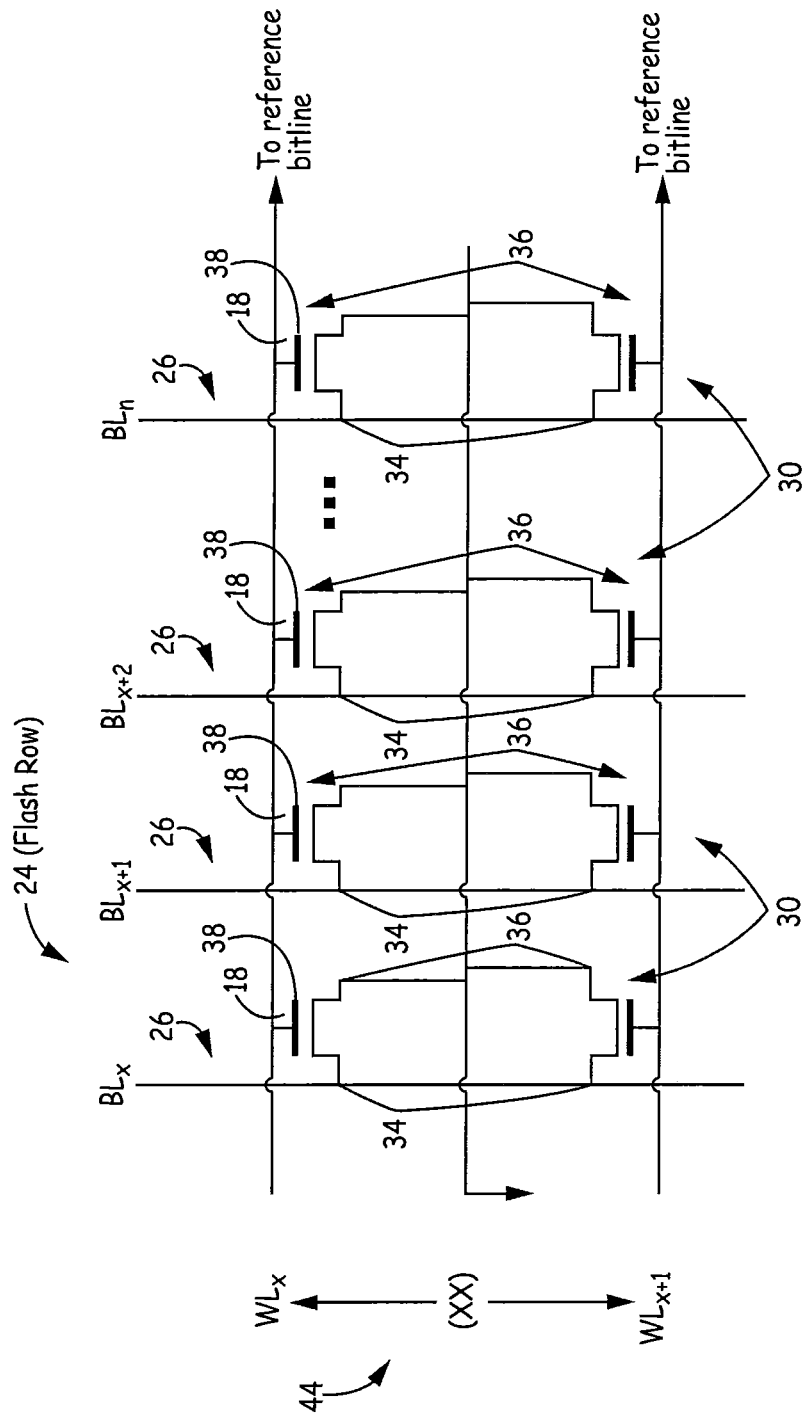


FIG. 4A

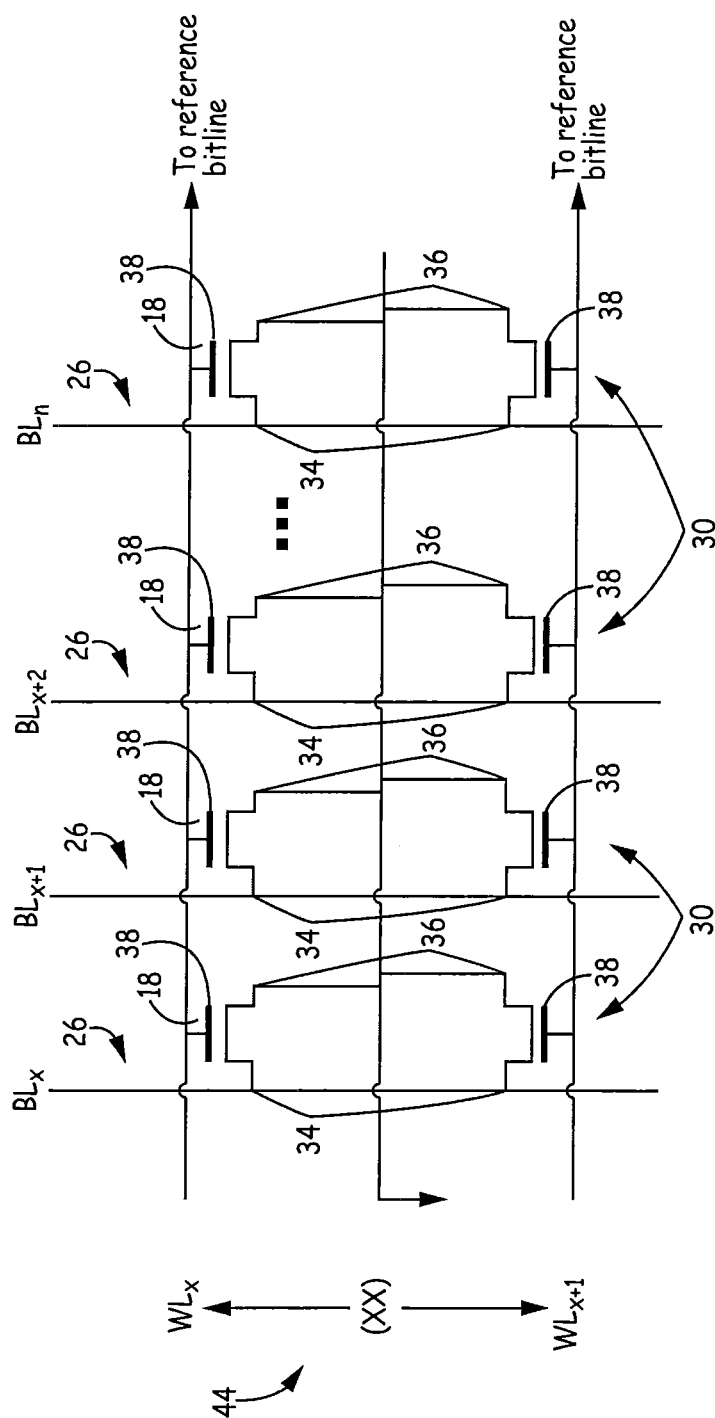


FIG. 4B

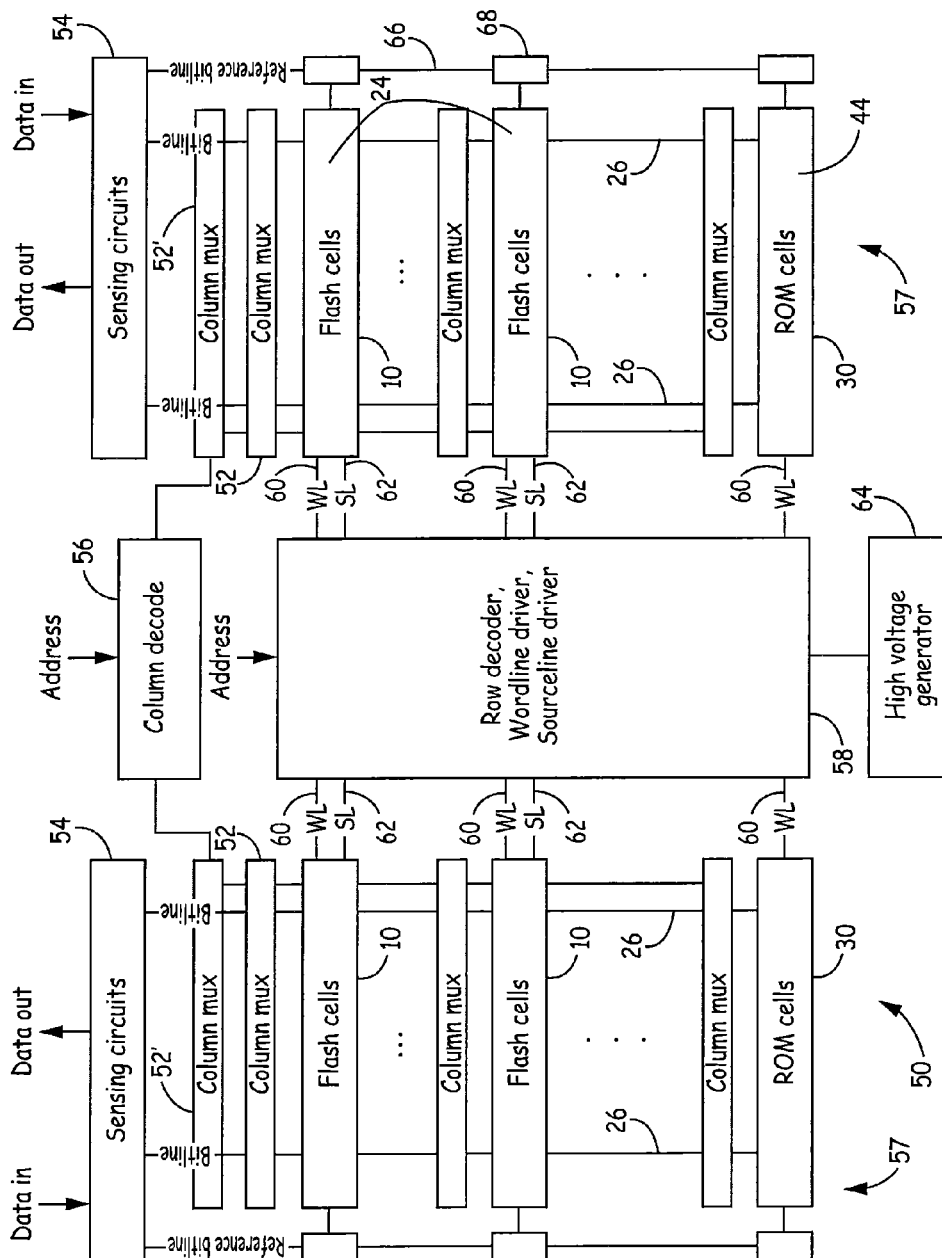


FIG. 5

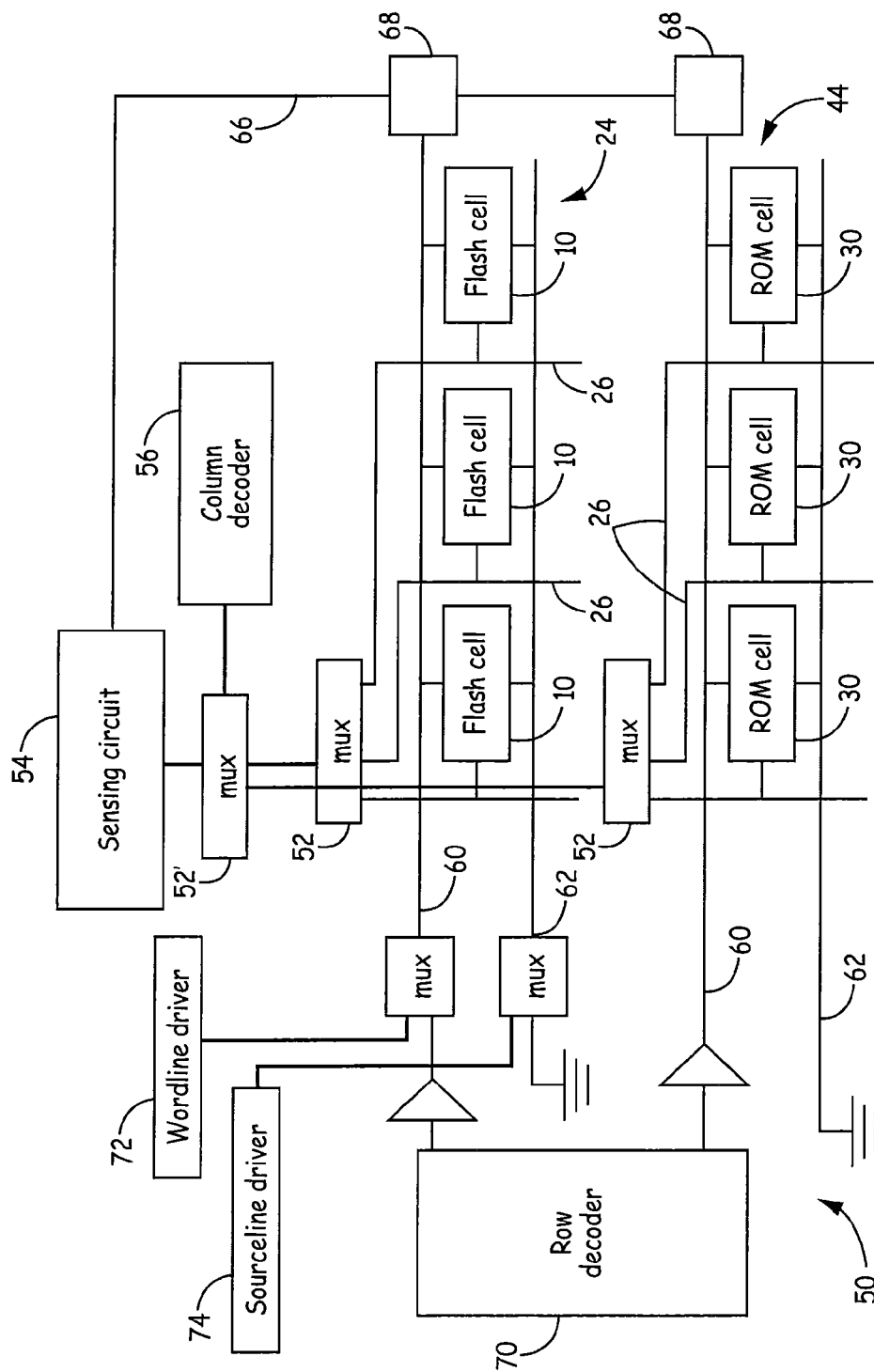


FIG. 6



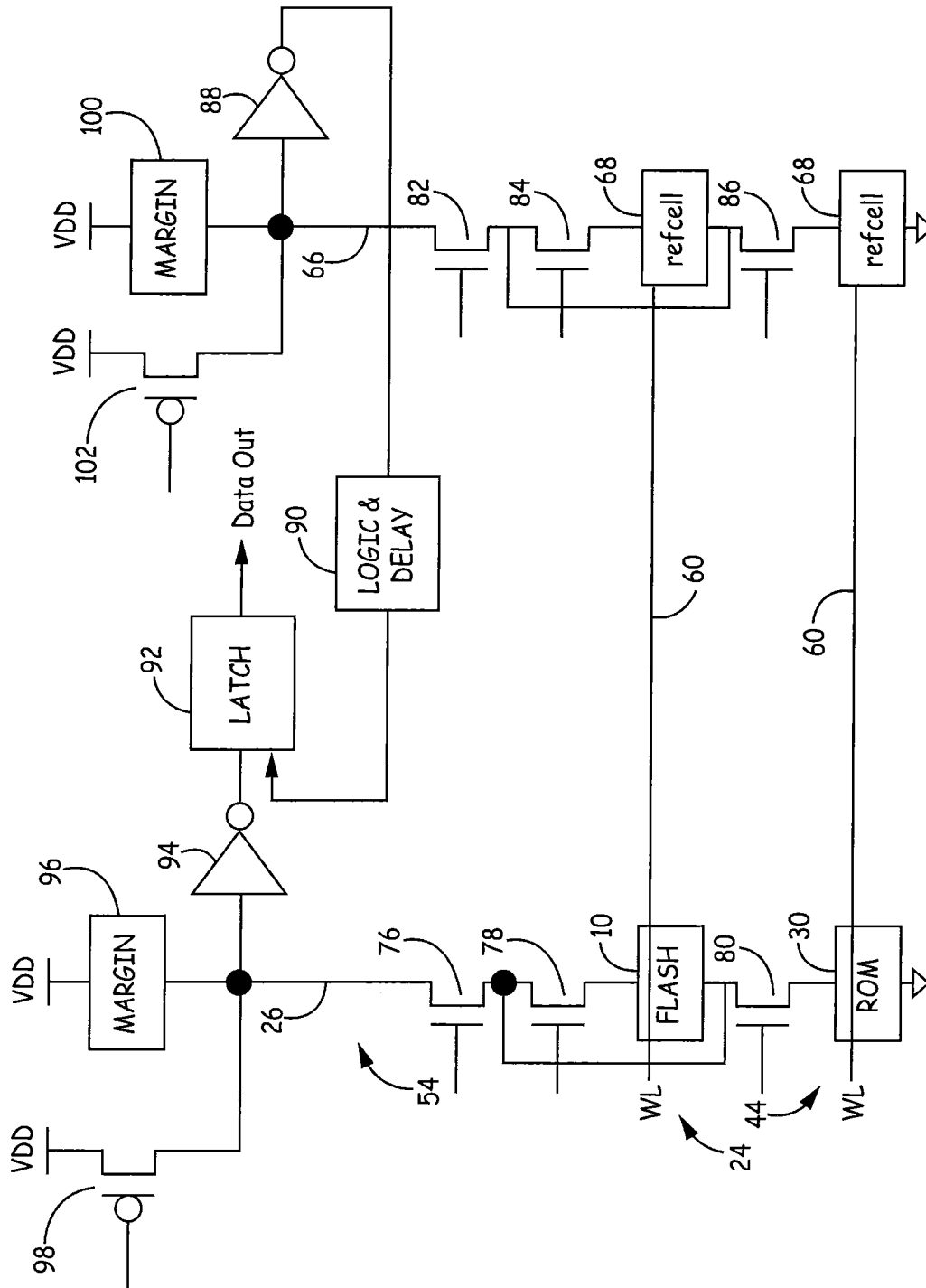


FIG. 7a

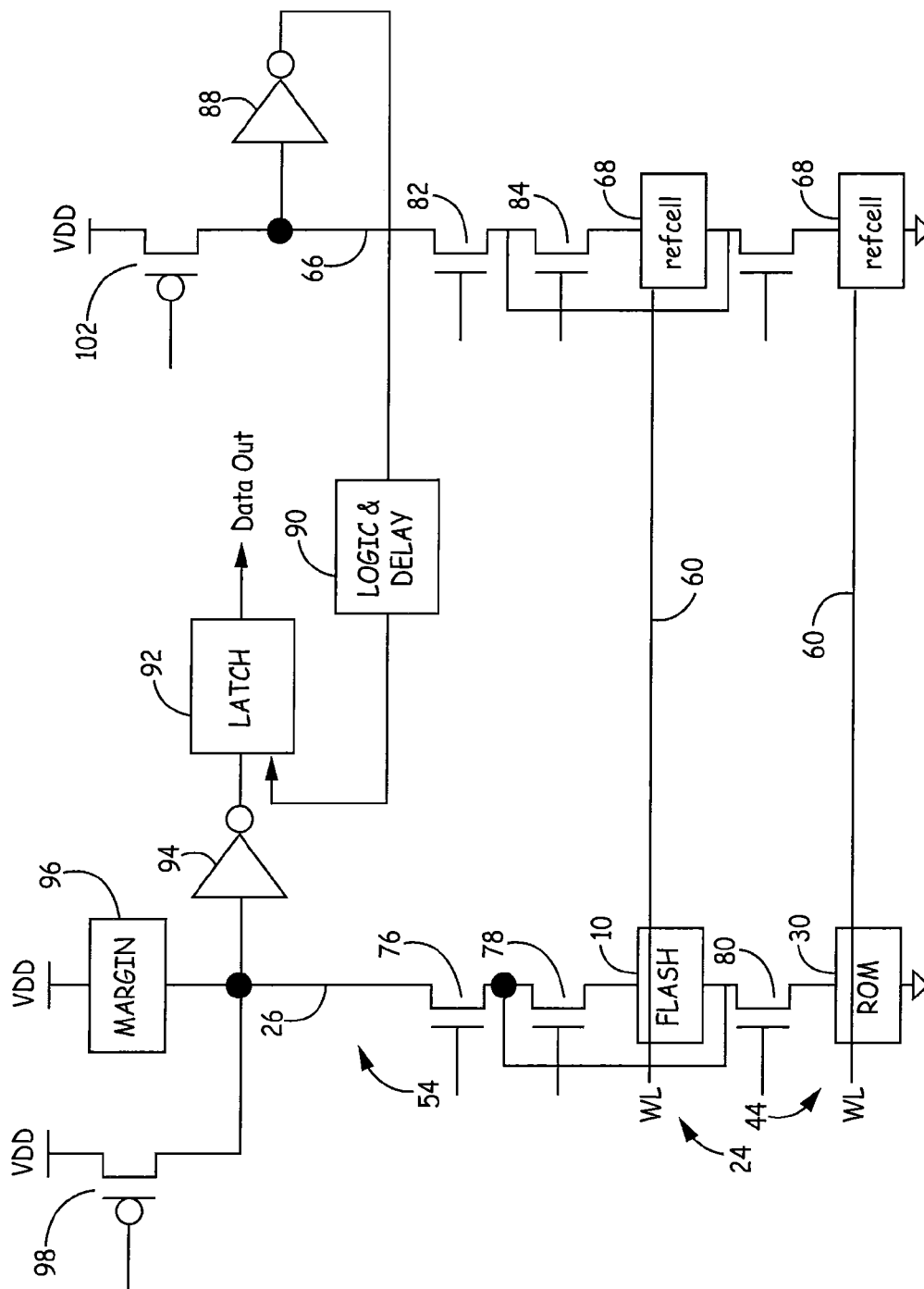
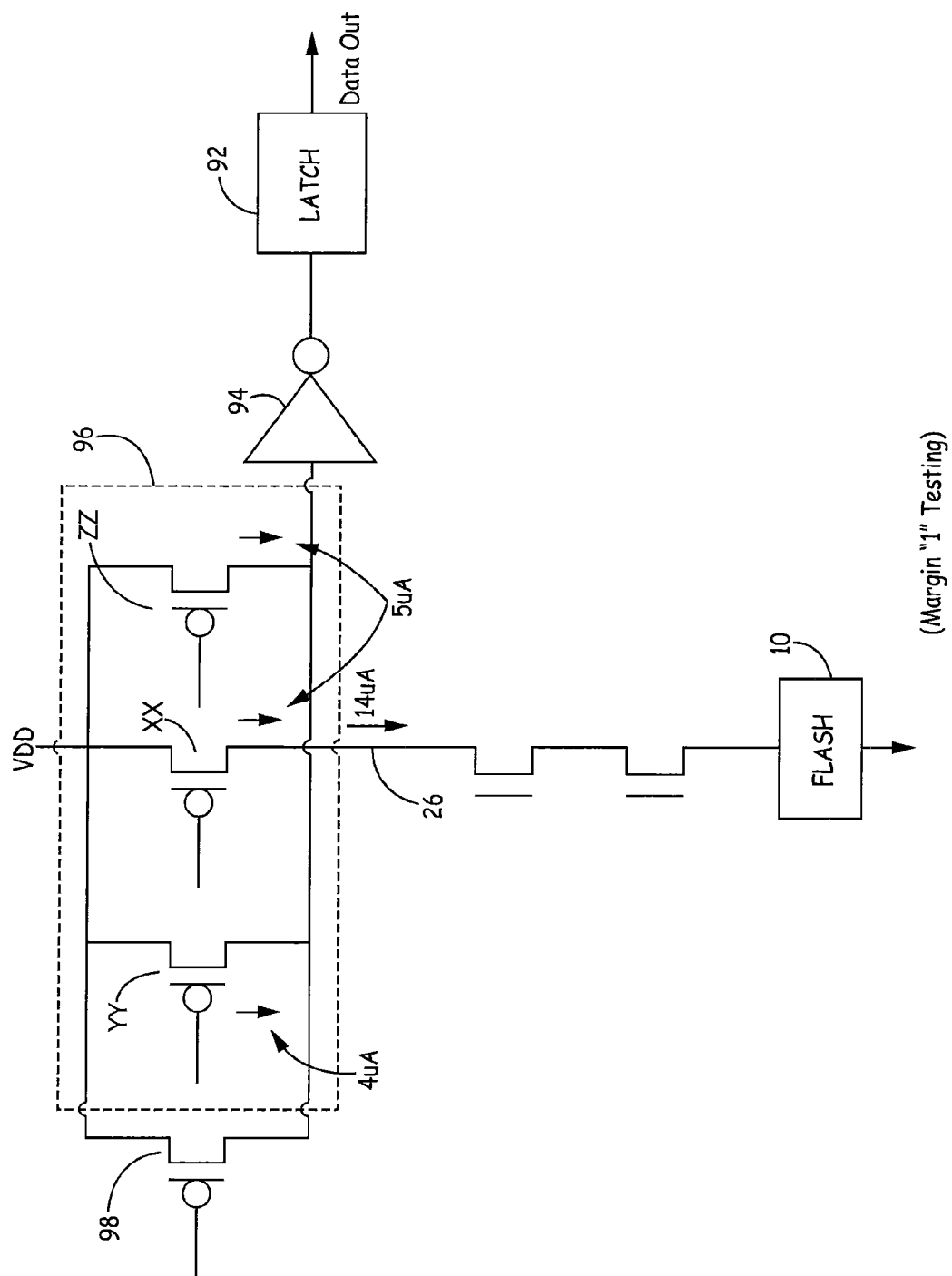


FIG. 7b



(Margin "1" Testing)

FIG. 8a

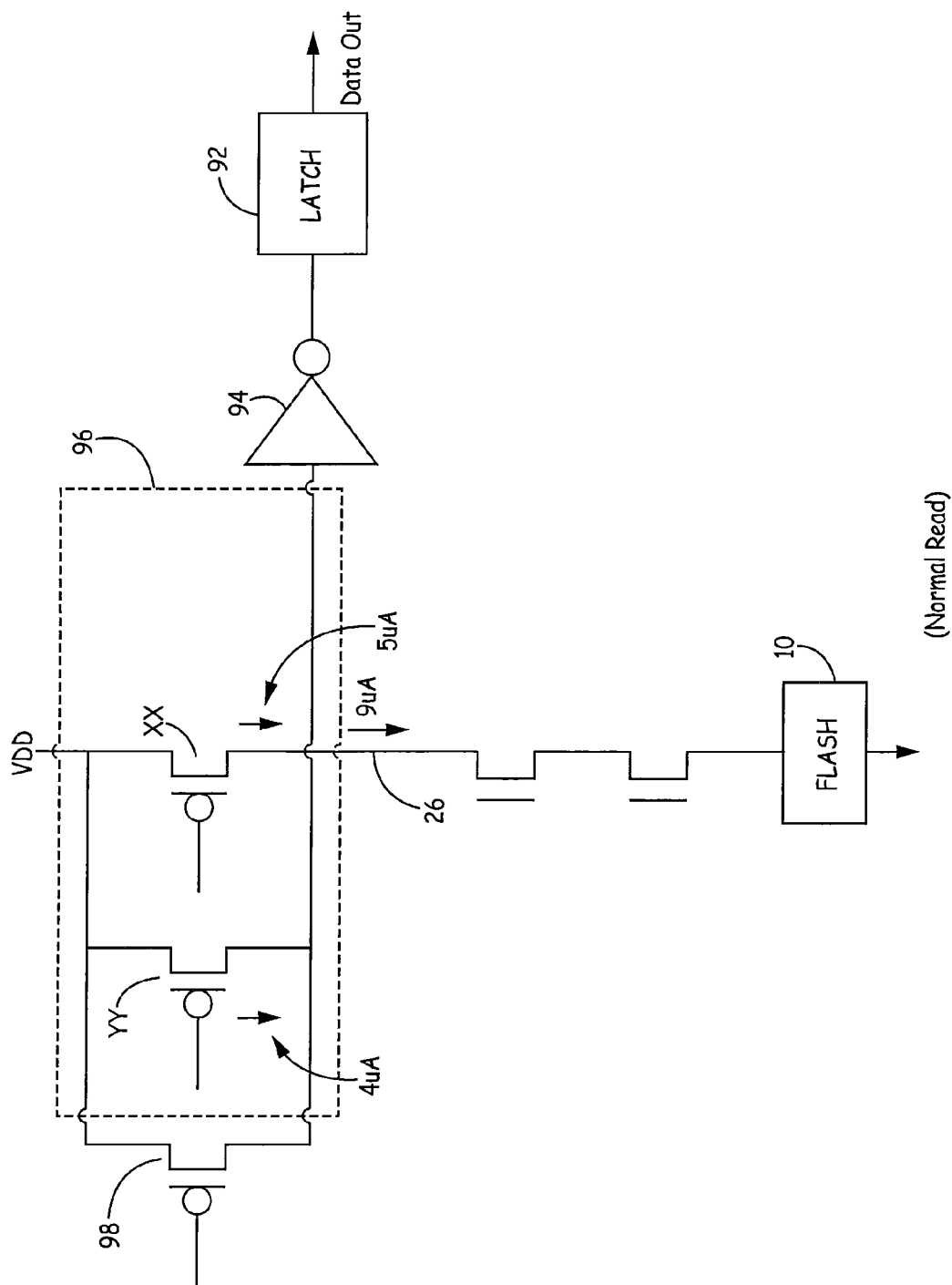
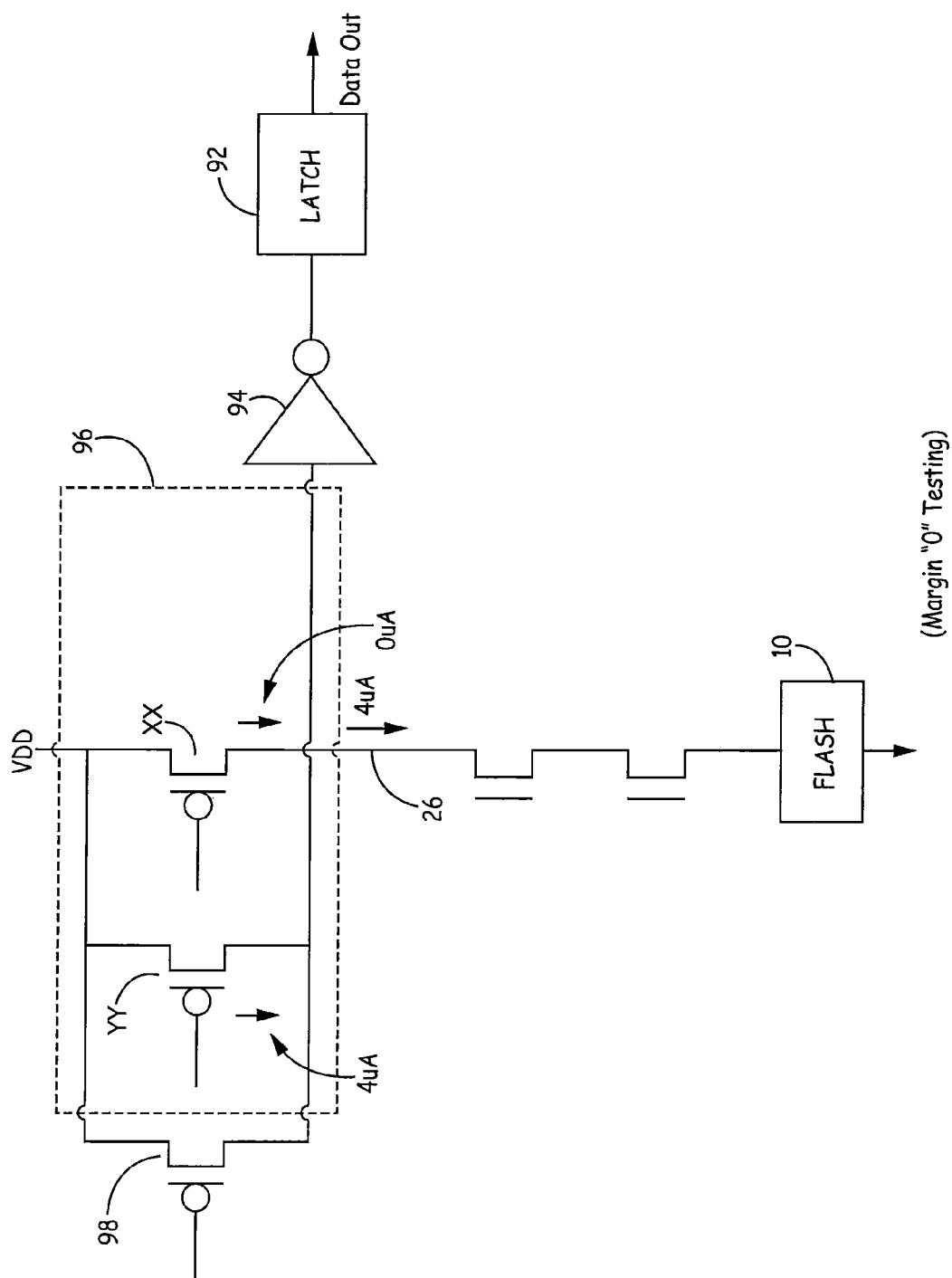


FIG. 8b



(Margin "0" Testing)

FIG. 8c

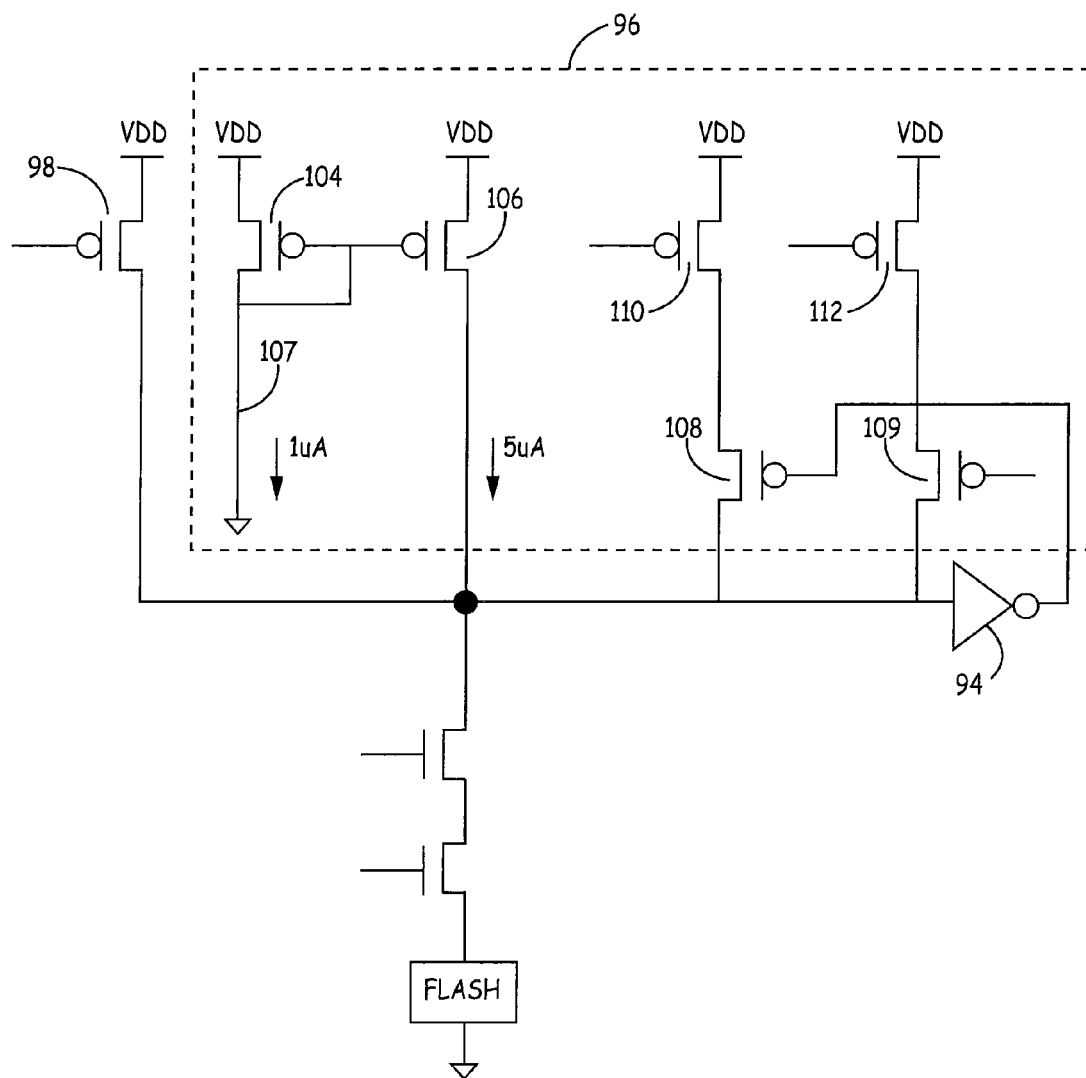


FIG. 9

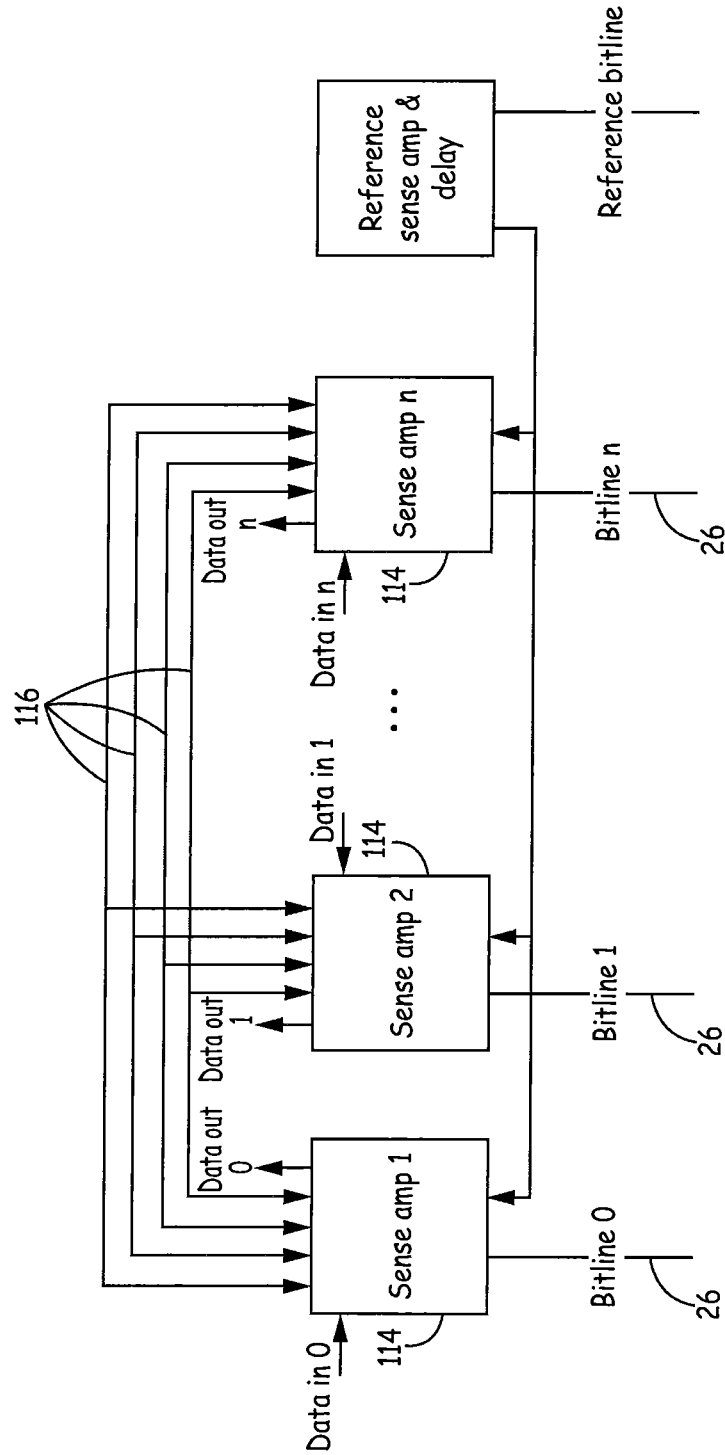


FIG. 10

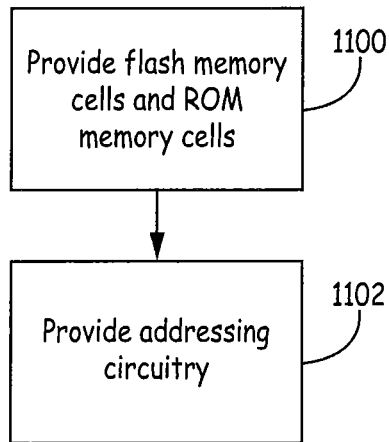


FIG. 11



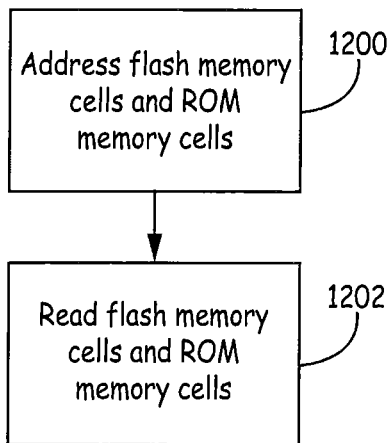


FIG. 12

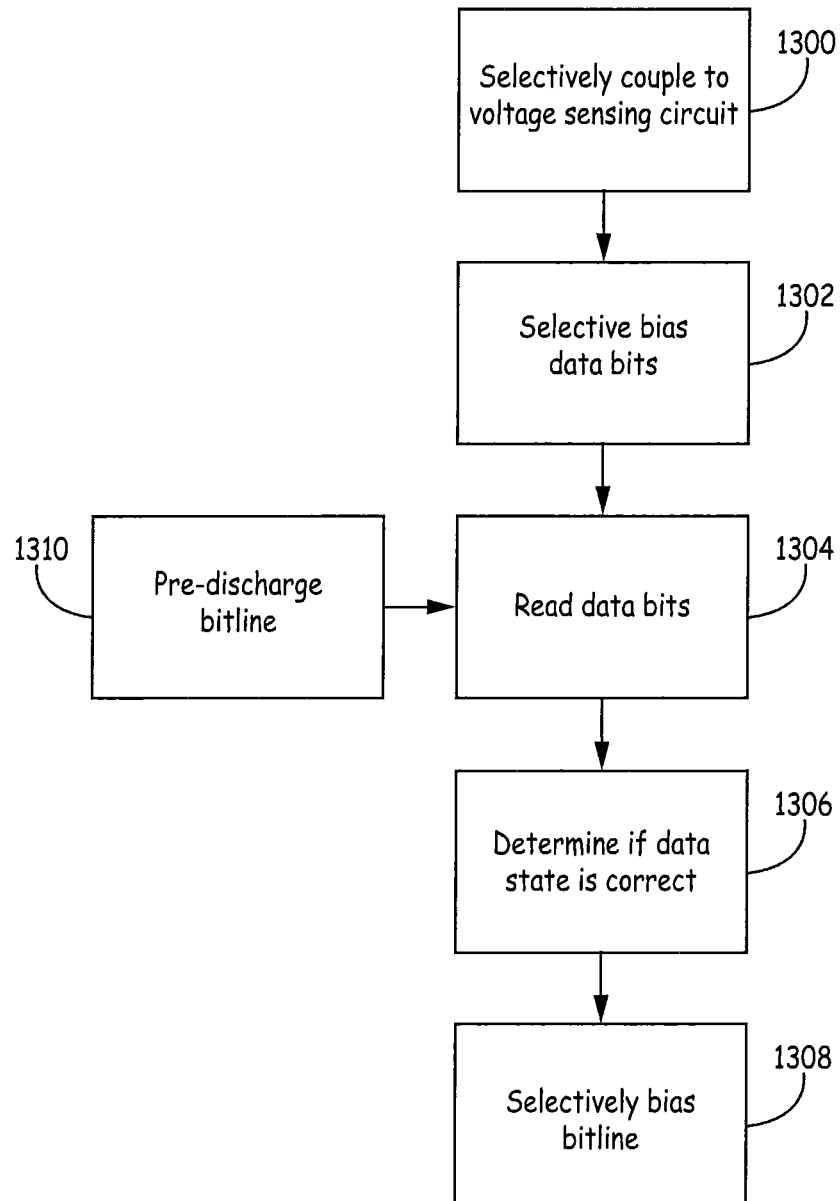


FIG. 13a

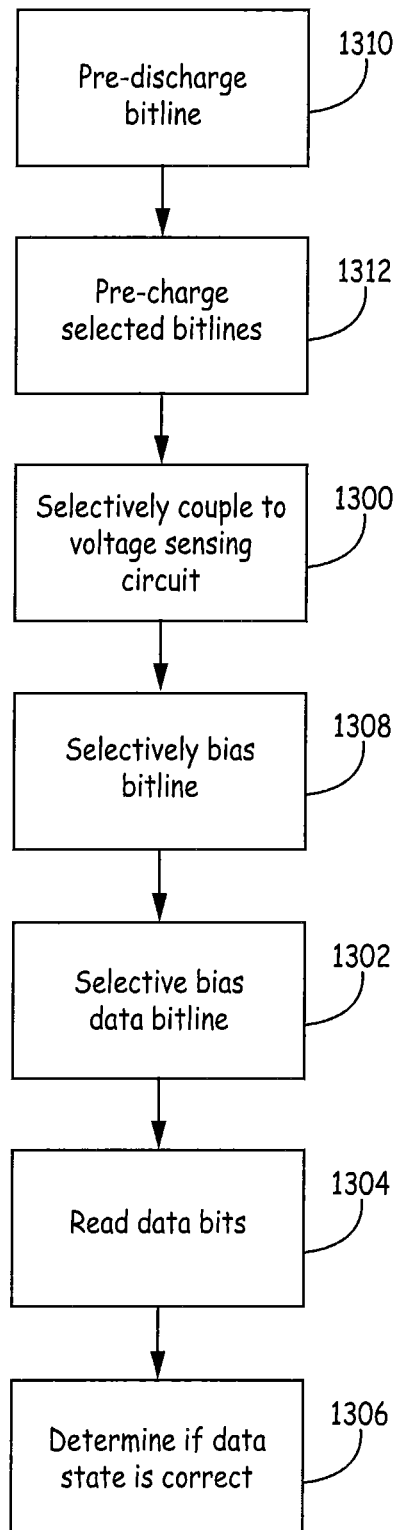


FIG. 13b

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## FLASH MEMORY WITH INTEGRATED ROM MEMORY CELLS

### FIELD

The present invention relates generally to memory arrays and, in particular, to memory modules incorporating both flash memory and ROM memory cells with common addressing circuitry.

### BACKGROUND

Memory arrays for storage, both short-term and long-term, of digital data are well known in the art. Various configurations and implementations of random access memory, known in the art as RAM, provide data storage in relatively small, efficient spaces in comparison to other memory technologies. RAM cells, however, utilize active electronic components, including transistors, to store digital data, resulting in an effectively immediate loss of the stored data in the event of a loss of power to the RAM cells. Hence, RAM memory is referred to as volatile memory.

Non-volatile memory cells, by contrast, maintain stored digital data for some extended period of time without need to maintain power to the memory cell. Such non-volatile memory cells include read-only memory cells, made from various semiconductor devices and known in the art as ROM, and flash memory cells, traditionally made from floating-gate transistors. Such non-volatile memory cells are electrically addressed and thus are faster to access than, for instance, mechanically addressed data storage systems such as magnetic storage (for instance, hard disks) and optical storage (for instance, CD-ROMs). However, non-volatile memory cells have historically contrasted unfavorably with volatile memory and mechanically addressed data storage in terms of cost, efficiency and utility. While both volatile and mechanically addressed storage is relatively cheap, densely packed and freely writeable and rewriteable, non-volatile memory has historically been expensive, large and with limitations on how many times the cell may be written to, as with a flash memory cell, or not subject to being rewritten at all, as with ROM memory cells.

On that basis, non-volatile, electronically addressed memory cells have historically been used sparingly in contrast with volatile memory and mechanically addressed non-volatile data storage. However, recent process improvements in non-volatile memory have made the use of non-volatile memory more viable. In particular, flash memory applications have become increasingly common, while new non-volatile memory techniques are in development.

The proliferation of flash memory has, however, created new challenges. In particular, while contemporary flash memory relatively reliable in comparison with historic flash memory, contemporary flash memory remains relatively unreliable in contrast with many other forms of memory, both volatile and non-volatile. While the relative unreliability of flash memory may be acceptable in consumer electronics, for instance, in life-critical applications, such as in medical devices, data unreliability may create challenges in using and implementing flash memory arrays.

### SUMMARY

Historically, the fact that flash memory cells and ROM memory cells utilize differing architecture has provided strong incentives to designers of individual memory arrays to make an array from one of flash memory and ROM memory,

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but not both. Differences in the physical dimensions of flash memory cells, made from floating-gate transistors, and ROM memory cells, made, for instance, from complimentary metal-oxide semiconductors, mean that flash and ROM memory cells cannot be formed into space-efficient lines of equivalent length and size. Differing power requirements to read and, in the case of flash memory cells, write to the cells creates comparatively large overhead and support electronics for a memory array with both flash and ROM memory cells. In addition, because of the above described differences in size and layout, flash and ROM memory arrays have historically incorporated varying addressing and sensing schemes, meaning that electronics configured to access individual cells have not been cross-compatible between flash and ROM memory arrays.

Owing to these above-detailed factors which tend to provide significant incentives not to combine flash and ROM, flash and ROM memory cells have not been incorporated within a single memory array incorporating common overhead circuitry. However, methodologies have been developed to permit the efficient combination of flash and ROM memory cells with a single array and incorporating at least some common overhead circuitry. Common overhead circuitry may include, but not be limited to, addressing circuitry, read circuitry, power supply, error detection and correction, data caching and timing structures. In applications in which the reliability and data integrity of flash memory cells may be inadequate, the benefits provided by rewriteable, non-volatile memory may nevertheless be attained when supplemented by relatively more reliable ROM memory.

In an embodiment, a memory array configured to store a plurality of data bits comprises a plurality of flash memory cells, a plurality of ROM memory cells and addressing circuitry operatively coupled to both the plurality of flash memory cells and the plurality of ROM memory cells, the addressing circuitry being configured to address both the plurality of flash memory cells and the plurality of ROM memory cells.

In an embodiment, the plurality of data are arranged in bitlines, the plurality of flash memory cells have a flash bitline address spacing, the plurality of ROM memory cells have a ROM bitline address spacing, and the flash bitline address spacing of the plurality of flash memory cells are approximately equal to the ROM bitline address spacing of the plurality of ROM memory cells.

In an embodiment, the memory array further comprises read circuitry operatively coupled to both the plurality of flash memory cells and the plurality of ROM memory cells, the read circuitry being configured to read both the plurality of flash memory cells and the plurality of ROM memory cells.

In an embodiment, the memory array is comprised of a single memory array and wherein the single memory array comprises both the plurality of flash memory cells and the plurality of ROM memory cells.

In an embodiment, the memory array further comprises overhead circuitry including at least one of a power source, a voltage generator and an addressing block, the overhead circuitry being shared by both the plurality of flash memory cells and the plurality of ROM memory cells.

In an embodiment, a method of providing a memory array configured to store a plurality of data bits comprises the steps of providing, in a single array, a plurality of flash memory cells and a plurality of ROM memory cells and providing addressing circuitry, operatively coupled to both the plurality of flash memory cells and the plurality of ROM memory cells, configured to address both the plurality of flash memory cells and the plurality of ROM memory cells.

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In an embodiment, the method further comprises the step of providing read circuitry, operatively coupled to both the plurality of flash memory cells and the plurality of ROM memory cells, the read circuitry being configured to read both the plurality of flash memory cells and the plurality of ROM memory cells.

In an embodiment, the method further comprises the step of providing overhead circuitry including at least one of a power source, a voltage generator and an addressing block, the overhead circuitry being shared by both the plurality of flash memory cells and the plurality of ROM memory cells.

In an embodiment, a method of using a memory array configured to store a plurality of data bits having, in a single array, a plurality of flash memory cells and a plurality of ROM memory cells comprises the steps of addressing both the plurality of flash memory cells and the plurality of ROM memory cells with addressing circuitry common to both the plurality of flash memory cells and the plurality of ROM memory cells and reading both the plurality of flash memory cells and the plurality of ROM memory cells with reading circuitry common to both the plurality of flash memory cells and the plurality of ROM memory cells.

#### FIGURES

FIGS. 1a and 1b are a simplified depictions of a typical flash memory cell;

FIG. 2 is a line of flash memory cells;

FIGS. 3a and 3b are simplified depictions of a typical ROM memory cell;

FIGS. 4a and 4b are lines of ROM memory cells;

FIG. 5 is a memory array or module having both flash memory cells and ROM memory cells;

FIG. 6 is a block diagram of the memory array or module of FIG. 5;

FIGS. 7a and 7b are block diagrams of a sensing circuit;

FIGS. 8a, 8b and 8c are illustrations of margin testing and read operations;

FIG. 9 is a schematic diagram of a margin bias circuit and a pull-up circuit;

FIG. 10 is block diagram of a sensing circuit;

FIG. 11 is a flowchart for providing a memory array;

FIG. 12 is a flowchart for using a memory array; and

FIGS. 13a and 13b are flowcharts for operating a memory array or module.

#### DESCRIPTION

FIG. 1a is a simplified depiction of a typical flash data bit or flash memory cell 10 known in the art. Throughout this description, flash data bit and flash memory cell are used interchangeably. An adaptation of a conventional metal-oxide substrate field effect transistor (MOSFET), a channel may be created in p-substrate 12 between n-source 14 and n-drain 16 by inducing a charge on gate 18. Unlike in a conventional MOSFET transistor, however, floating gate 20 is incorporated between dielectric layers 22 between gate 18 and p-substrate 12. The creation of a voltage on gate 18 causes floating gate 20 to store electrons which, owing to the presence of dielectric layers 22, do not readily escape floating gate 20. The presence of the charge in floating gate 20 causes a predictable variance in the voltage threshold of flash memory cell 10 which may be conventionally detected as part of a read operation. The ability of flash memory cell 10 to store digital information long term may, by consequence, be dependent on the ability of floating gate 20 to maintain an applied charge without substantial degradation over time.

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The various components of flash memory cell 10 may be sized according to contemporary processes. In an embodiment, flash memory cell 10 is formed according to the 0.25 micrometer process. In such an embodiment, flash memory cell 10 has 0.9 micrometer by 1.20 micrometer dimensions.

FIG. 1b is a depiction of an exemplary physical embodiment of flash memory cell 10. In an exemplary embodiment, flash memory cell 10 is read by placing gate 18 at two (2) Volts, drain 16 at 1.4 Volts and n-source 14 at zero (0) Volts, and the resultant current from drain 16 to source measured; if the drain-to-source current is less than approximately one (1) microampere then a logical "0" is stored in cell 10, while if the drain-to-source current is greater than approximately ten (10) microamperes then a logical "1" is stored in cell 10. In an embodiment, flash memory cell 10 may be programmed by placing gate 18 at 1.7 Volts, n-drain 16 at 0.6 Volts and n-source 14 at 9.5 Volts. In an embodiment, flash memory cell 10 may be erased by placing gate 18 at thirteen (13) Volts, n-drain 16 at zero (0) Volts and n-source 14 at zero (0) Volts.

FIG. 2 is an exemplary application of multiple flash memory cells 10 being incorporated within line 24 to provide multi-bit data storage. N-sources 14 are shorted to a source line (YY) and N-drains 16 are coupled to bitlines 26. Gates 18 are coupled to wordlines (XX). In so doing, a particular bit of each of multiple data words (for instance, bit 0 of each of words 0 and 1) may be accessed on bitline 26 and the wordline through a read operation. By repeating this structure on multiple additional lines 24, additional bits of the words of illustrated line 24 (for instance, bit 0 of words 2 and 3) may be accessed for reading and writing. In an embodiment, each line 24 has two thousand ninety six (2,096) cells 10, providing a flash bitline address spacing of two thousand ninety six (2,096) per line 24. In an embodiment, each bitline 26 connects to two hundred fifty-six (256) flash data bits 10.

FIG. 3a is a simplified depiction of a typical electrically programmable read-only memory (EPROM) data bit or memory cell 30 known in the art. Throughout this document, the terms read-only memory cell, read-only data bit, ROM or EPROM data bit, ROM or EPROM memory cell are used interchangeably. While the electrically programmable read-only memory cell 30 is shown for illustrative purposes, read-only memory cells which are not electrically programmable may also be utilized, as illustrated in FIG. 3b. In various embodiments, ROM data bit 30 is not electrically programmable. Like flash memory cell 10, ROM data bit 30 is also an adaptation of a conventional MOSFET, with a channel being created in p-substrate 32 between n-source 34 and n-drain 36 by inducing a charge on gate 38.

In contrast with floating gate 20 of flash memory cell 10, which is commonly comprised of conventional polycrystalline silicon as used in MOSFET, floating gate 40 of EPROM data bit 30 is doped so as to resist changes in floating gate's 40 electric potential after placing floating gate 40 in a particular logical state. For instance, while floating gate 40 may be switched so that ROM data bit 30 stores a logical "1" to a logical "0", the doping of floating gate 40 may prevent switching from a logical "0" to a logical "1". In various embodiments, floating gate 40 is doped with phosphorous. While dielectric layers 42 may be incorporated as in flash memory cell 10, dielectric layers 42 may not be required to maintain the electric potential of floating gate 40. In embodiments which are not electrically programmable, and thus do not incorporate floating gate 40, a contact or lack of contact may set the state of ROM memory cell 30 as known in the art.

The various components of ROM data bit 30 may be sized according to contemporary processes known in the art. In an embodiment, cell 30 is formed according to the 0.25

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micrometer process. In such an embodiment, cell 30 has 1.375 micrometer by 0.9 micrometer dimensions.

FIGS. 4a and 4b are exemplary applications of multiple ROM data bits 30 being incorporated within line 44 to provide multi-word data storage. In FIG. 4a, N-drain 34 and n-source 36 of adjacent ROM data bits 30 are coupled to bitlines 26 and ground respectively while gates 38 are coupled to wordlines XX). In so doing, a particular bit of each of multiple data words (for instance, bit 0 of each of words 0-1) may be accessed on bitline 26 through a read operation on a word selected by the wordline. By repeating this structure on multiple additional lines 44, additional bits of the words of illustrated line 44 (for instance, bit 0 of words 2-3) may be accessed for reading and writing. In an embodiment, each line 44 includes two thousand ninety six (2,096) cells 30, providing a ROM bitline address spacing of two thousand ninety six (2,096) per line 44. In an embodiment, each bitline 26 corresponds to two hundred fifty-six (256) ROM data bits 30.

The various embodiments described above are merely exemplary, as various additional types of flash data bits 10 are known in the art and myriad ROM data bits 30 are also known in the art. Similarly, flash data bits 10 and ROM data bits 30 are commonly organized into lines and columns according to various techniques dependent on the circumstances of the data bits themselves and the circumstances of their use. However, incorporating flash data bits 10 according to a common addressing scheme, i.e., common schemes by which bitlines 26 and wordlines 44 are assigned between and among flash data bits 10 and ROM data bits 30, due to the differing characteristics of flash data bits 10 and ROM data bits 30, may make the resultant memory relatively inefficient. In particular, because flash data bits 10 and ROM data bits 30 have differing dimensions, common addressing schemes may tend to create wasted space on a chip. Similarly, because flash data bits 10 and ROM data bits 30 have different performance characteristics, such as the amount of time needed to read data from one or the other, utilizing non-alike data bits within a common addressing scheme may, unless particularly addressed, create unreliabilities.

As illustrated, line 44 has shared N-sources 36 coupled to ground. In various embodiments, ROM memory cells 30 are programmed by either including or not including a drain connection for each ROM memory cell 30. If there is a drain connection, the ROM memory cell may conduct current when selected. If there is no drain connection, the ROM memory cell may conduct no current when selected. The drain connection can be made with many semiconductor materials. In one embodiment, the connection is a contact. In other embodiments, for example, the connection is a via, metal or diffusion layer.

FIG. 5 is a block diagram of memory array or module 50 which is a single memory array incorporating both flash data bits 10 (not shown with particularity) and ROM data bits 30 (not shown with particularity) according to a common addressing scheme. Flash data bits 10 are organized into lines 24 and ROM data bits are organized into lines 44, as discussed above. Multiple bitlines 26 extend from rows 24, 44 to column multiplexor 52 as known in the art. Sensing circuits 54 are read circuitry utilized to detect information placed on bitlines 26 and thus determine what the contents of a particular data bit are, irrespective of whether the data bit is a flash data bit 10 or a ROM data bit 30.

Column decode block 56, similar to that of column decoders known in the art, is overhead circuitry that controls a particular column multiplexor 52' to select each bitline 26 based on the column address as input into column decode block 56. It is noted that in the illustrated embodiment,

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memory module 50 is divided into halves 57, each with its own addressing circuitry such as multiplexors 52, 52' and read circuitry such as sensing circuits 54, to promote simplicity in such circuitry. In various alternative embodiments, memory module 50 may not be divided at all and thereby not multiple blocks of, for instance, multiplexors 52, 52' and sensing circuitry 54, or may be divided into more than two blocks with an accompanying multiplexors 52, 52' and sensing circuitry 54 for each block.

Line electronics 58 is overhead circuitry which includes a row decoder, wordline driver and sourceline driver. The row decoder, as is familiar in the art, is configured to select a particular row or line 24, 44 based on the input address. The wordline driver and the sourceline driver combine to create a voltage differential between wordline 60 and sourceline 62, respectively. Wordline 60 and sourceline 62 provide a voltage differential over flash memory cells 10 in order to read or write the flash memory cell, as known in the art. As ROM memory cells 30 cannot be written to, only the wordline driver is coupled to a wordline 60 ROM memory cells 30. The presence of a high voltage, such as a reference voltage, or a low voltage, such as a ground voltage, selects each row 24, 44 for the purposes of reading the data from the cells 10, 30 of the particular row 24, 44. In combination with the applied voltage on bitlines 26 from sensing circuitry or sensing circuit 54, individual cells 10, 30 may be selectively activated for reading and, in the case of flash memory cells 10, writing.

High voltage generator 64 is overhead circuitry configured to supply voltages for programming and erasing flash memory cells 10. In an embodiment, nine and one half (9.5) Volts is used for programming flash memory cells 10 and thirteen (13) Volts is used for erasing flash memory cells 10. In an embodiment, high voltage generator 64 comprises at least one 2.0 Volt supply coupled to a Dickson charge pump to provide the programming and erasing voltages as appropriate.

Reference bitline 66 is structurally similar to bitlines 26. However, reference bitline 66 is physically positioned at the far end of each row 24, 44 relative to line electronics 58. As will be discussed further below, the positional distance of reference bitline 66 may provide a deliberate delay in the operation of sensing circuit 54 in reading data following a selection of a particular memory cell 10, 30 for reading by column decode block 56 and the wordline driver. Because of the physical differences between flash memory cells 10 and ROM memory cells 30, the timing of activation of such cells 10, 30 may vary with respect to one another.

In certain circumstances, because ROM memory cells 30 are physically larger than flash memory cells 10, it may take longer for signals to propagate down wordlines 60 on ROM rows 44 than on flash rows 24. Alternatively, ROM memory cells 30 may access faster than flash memory cells 10 owing to a shorter effective channel length on ROM memory cells 30 compared with flash memory cells 10. This causes the read current to be higher and the sense amp triggers faster as does the circuit that times the read. As a result, the timing by which a selected flash memory cell 10 may place data on its bitline 26 during a read operation may occur later in time than the same read operation on a corresponding ROM memory cell 30. Thus, the twelfth flash memory cell 10 in row 24 may place its data on its corresponding bitline 26 slower than the twelfth ROM memory cell 30 in row 44. Because the twelfth flash memory cell 10 and the twelfth ROM memory cell 30 of each row 24, 44 utilize the same bitline 26, sensing circuits 54 may not, without an additional indication, be able to predict when the signal on the twelfth bitline 26 will be accurate.

When a signal propagates from the wordline driver, because the memory cell 10, 30 is located physically closer to the wordline driver than reference bitline 66, it may inherently be the case that the particular memory cell 10, 30 is activated before reference bitline cell 68, a reference memory cell 10 or 30, as appropriate to the row 24, 44 in which it is located. In certain embodiments, reference bitline cell 68 may be physically sized differently than flash memory cells 10 and ROM memory cells 30 so as to trigger more slowly than flash memory cells 10 and ROM memory cells 30. In an embodiment, reference bitline cell 68 is a dummy memory cell not configured to store data.

It is known that once reference bitline 66 is activated, whatever the selected memory cell 10, 30 may be, the selected memory cell 10, 30 should have been activated, allowing sensing circuits 54 to read the data on the bitline 26 corresponding to the selected memory cell 10, 30. Consequently, activation of reference bitline 66 provides an indication to sensing circuit 54 that the data on the selected bitline 26 may be accurately read. As a result, reference bitline 66 provides the same sensing circuit 54 to read both flash memory cells 10 and ROM memory cells 30.

FIG. 6 is a block diagram illustrating detail of memory module 50, illustrating individual flash memory cells 10 and ROM memory cells 30. Row decoder 70 includes selection circuitry to select lines 24, 44 for wordline driver 72 and sourceline driver 74. Bitlines 26 are selected by way of column decode block 56 and column multiplexors 52, 52'. Individual cells 10, 30 are positioned physically closer to row decoder 70 than is reference bitline cell 68. As a result, flash memory cells 10 and ROM memory cells 30 may utilize a common addressing and sensing scheme, while flash memory cells 10 may utilize a common writing scheme.

FIG. 7a is a simplified block diagram of an embodiment of sensing circuit 54 and illustrative memory cells 10, 30 coupled to sensing circuit 54 by way of bitline 26. It is noted that for simplicity only a single bitline 26 is illustrated, though in the actual implementation there would be as many rows 24, 44 as are present in memory module 50 (FIG. 5) and as many bitlines 26 as there are columns in rows 24, 44. Switch 76 may be utilized to select a particular bitline 26 for reading while switches 78, 80 may be utilized to select a particular cell 10, 30 on the particular bitline 26 for reading. Switches 76, 78 and 80 are detail of column multiplexors 52 and 52'.

Reference bitline cells 68 are coupled to reference bitline 66 and are selectable via switches 82, 84, 86 in a manner similar to that of bitline 26. Reference bitline 66 is coupled to inverter 88 and from there to logic and delay block 90 and latch 92. Latch 92 is configured to store the result of sensing the voltage on bitline 26 by way of inverter 94. Logic and delay block 90 operates latch 92 based on the change in reference bitline 66.

As is known in the art, in order to read cells 10, 30, an electronic stimulus is applied to cells 10, 30 and the effect of cells 10, 30 on the input electronic stimulus is measured. In an embodiment, cells 10 and 30 are variably biased with current, resistance or both and when wordline 24 or 44 is selected the voltage on bitline 26 is measured by way of inverter 94 and stored in latch 92. If the charge stored in cell 10, 30 is such that cell 10, 30 conducts current and functions as a closed circuit, the voltage on bitline 26 may be low, that is reflected digitally by inverter 94. Likewise, if the charge stored in cell 10, 30 is such that cell 10, 30 conducts little current, the voltage on bitline 26 may be high, which may be reflected digitally by inverter 94. In an embodiment, the voltage on bitline 26 has a maximum of approximately two (2) Volts and a minimum of

approximately zero (0) Volts, while inverter 94 has a threshold of between approximately 0.7 Volts to one (1) Volt.

Consequently, if the voltage on bitline 26 is less than approximately one (1) Volt inverter 94 may register that a logical "1" is in the cell 10, 30 influencing bitline 26 by outputting a high voltage to latch 92. If the voltage on bitline 26 is greater than approximately one (1) Volt inverter may register that a logical "0" is in the cell 10, 30 influencing bitline 26 by outputting a low voltage to latch 92.

Particularly regarding flash memory cells 10, though also in certain instances with respect to ROM memory cells 30, certain cells 10 may lose their ability to store charge on floating gate 20, effectively rendering cell 10 inoperative and losing the data stored in cell 10. To manage the reliability of cells 10, margin bias circuit 96 provides variable bias current to test a reliability of cells 10, 30.

Margin bias circuit 96, in the illustrated embodiment a hold circuit based on P-channel transistors (below) is configurable to provide testing to assess not merely the ability of cell 10 to store a logical "0" and a logical "1", but rather whether cell 10 only barely has the ability to store a logical "0" or logical "1", or if cell 10 has some margin in its ability to store a logical "0" or a logical "1". In particular, if cell 10 can store a logical "0" or logical "1", but cannot demonstrate margin in the ability to store logical "0" or logical "1", data stored in cell 10 may be preserved by being transferred to another cell 10 while the cell 10 which failed the margin test may be deemed unreliable and, in an embodiment, not utilized for further data storage.

Pull-up circuit 98 forces bitline 26 in a known, charged state, in an embodiment two (2) Volts. Consequently, a read operation on cell 10 may be conducted such that the state on bitline 26 changes when floating gate 20 is charged. Thus, the charge on floating gate 20 must be strong enough to permit the flow of current over cell 10 to change the state of bitline 26 in order to store a logical "1".

Margin bias circuit 96 is configurable to provide current to keep bitline 26 high after pull-up circuit 98 is switched off. In a conventional read operation to determine what is stored in cell 10, in an embodiment, margin circuit 96 contains two P transistors YY and XX. P transistor YY and P transistor XX provide a base amount of current to keep bitline 96 high. In an embodiment, P transistor YY provides approximately four (4) microamperes of current to bias bitline 26. In an embodiment, P transistor XX provides approximately five (5) microamperes of current to bias bitline 26. Consequently, in such an embodiment, to store a logical "1", cell 10 must be able to pass or "sink" at least nine (9) microamperes of current to change the voltage state of bitline 26 sufficient to be recorded by inverter 94. If cell 10 passes or sinks less than nine (9) microamperes of current, a logical "0" will be stored.

In an embodiment, margin bias circuit 96 is configured to conduct a test on cell 10 to determine if cell 10 has margin in its ability to store a logical "0". In an embodiment, margin bias circuit 96 is configured to provide four (4) microamperes of current to conduct a test of cell's 10 ability to store a logical "0". If the charge stored in floating gate 20 is not strong enough to permit cell 10 to sink four (4) microamperes in total four (4) microamperes from P transistor YY and zero (0) microamperes from P transistor XX, then cell 10 may be deemed to have sufficient margin to reliably continue to store a logical "0".

In various alternative embodiments, margin bias circuit 96 is configured to provide different amounts of current dependent on the characteristics of cell 10 and the degree of margin that is desired for a cell 10 to qualify as reliable. In the above embodiment, margin bias circuit 96 is configured to provide four (4) microamperes to test cell's 10 ability to store a logical

“0”; as cell 10 would need to sink less than four (4) microamperes to qualify as being reliable. The above principles apply to demonstrate greater or lesser amounts of margin.

The ability of cell 10 to store a logical “1” operates on a related principle. To store a logical “1”, floating gate 20 must store enough charge that cell 10 can sink more current than the amount being forced onto bitline 26 and thereby allow the voltage on bitline 26 to drop beyond that which registers as a low voltage for inverter 94.

In a conventional read mode, then, when margin bias circuit 96 provides, in the above embodiment, four (4) microamperes on P transistor YY and five (5) microamperes on P transistor XX, cell 10 must sink more current than the combined nine (9) microamperes and therefore force bitline 26 low. In order to test for the reliability of cell 10 to store a logical “1”, margin bias circuit 96 provides an additional five (5) microamperes of current into bitline 26. Therefore, cell 10 must now pass or sink a combined fourteen (14) microamperes. The additional five (5) microamperes is forced into bitline 26 by P transistor ZZ. If cell 10 can sink the original nine (9) microamperes plus the additional current provided by P transistor ZZ, the cell is tested as having sufficient margin to be considered reliable.

In various alternative embodiments, margin bias circuit 96 provides different amounts of current, resulting in different amounts of margin for logical “0” and logical “1”.

In further alternative embodiments, the amount of current margin bias circuit 96 provides is selectable in percentage terms. For instance, a margin “0” test may be conducted to provide a selectable percentage margin over a normal read operation. In the above embodiment, a margin “0” test of four (4) microamperes provides an indication of approximately fifty (50) percent of margin over the nine (9) microamperes of a normal read operation. Similarly, a margin “1” test may be conducted to provide a selectable percentage. In an embodiment, margin bias circuit 96 may be configurable to provide current in order to indicate variable percentage of margin.

In various embodiments, pull-up circuit 98 is not provided, and margin bias circuit 96 provides all intended current biasing on bitline 26. In such embodiments, margin bias circuit 96 simply provides a variable amount of bias current on bitline 26, in the above embodiment four (4) microamperes, nine (9) microamperes and fourteen (14) microamperes for margin “0” testing, normal read operations and margin “1” testing, respectively.

In certain embodiments, a current which induces a voltage may also be referenced in terms of the resistance which is utilized to induce the current. Thus, margin bias circuit 96 and pull-up circuit 98 may be understood to impart a bias resistance rather than, or in addition to the bias current described herein. The resistance would be determined by the size of the transistors in each circuit.

Reference hold circuit 100 and reference pull-up circuit 102 provide related testing of reference bitline cells 68 as margin bias circuit 96 and pull-up circuit 98 provide for cells 10. In an alternative embodiment illustrated in FIG. 7b, reference hold circuit 100 is not included and pull-up circuit 102 provides pre-charging of reference bitline 66. As, in various embodiments, reference bitline cells 68 are electrically similar or identical to those of cells 10, pull-up circuit 102 is configured to force reference bitline high and reference hold circuit 100 may variably provide five (5) eighth (8) and thirteen (13) microamperes for margin “0” testing, normal reading and margin “1” testing, respectively. Margin bias circuit 96 and reference hold circuit 100 may be selectable from any

electronic circuitry known in the art which can reliably be configured to provide a predetermined and selectable amount of current.

FIGS. 8a, 8b and 8c are exemplary block diagrams of a portion of FIGS. 7a and 7b illustrating margin “1” testing, a normal read operation and margin “0” testing, respectively. In all of FIGS. 8a, 8b and 8c, pull-up circuit 98 precharges bitline 26 to VDD. In FIG. 8a, margin bias circuit 96 is configured for a margin “1” test of cell 10 and produces fourteen (14) microamperes of current. Cell 10 may be determined to have adequate margin for reading a logical “1” if the voltage input to inverter 94 remains below the transition threshold of inverter 94.

In FIG. 8b, margin bias circuit 96 is configured for a normal read operation and produces nine (9) microamperes of current. Cell 10 may be expected to have accurately displayed the digital bit stored therein and the inverter may be deemed to have accurately reported the nature of the digital bit stored therein based on the voltage on bitline 26 being above or below the transition threshold of inverter 94, as the case may be.

In FIG. 8c, margin bias circuit 96 is configured for a margin “0” test of cell 10 and produces four (4) microampere of current. Cell 10 may be determined to have adequate margin for reading a logical “0” if the voltage input to inverter 94 remains above the transition threshold of inverter 94.

FIG. 9 is a schematic diagram of margin bias circuit 96 and pull-up circuit 98. Margin bias circuit 96 includes P-channel metal oxide semiconductor transistors 104, 106 (or “PMOS” transistors, as known in the art) sized to mirror five (5) microamperes of current from current source 107. In an embodiment, transistors 104 and 106 are approximately one (1) micrometers by two hundred eighty (280) nanometers and approximately five (5) micrometer by two hundred eighty (280) nanometers, respectively. In an embodiment, when performing margin “0” testing, a 2.0 Volt supply is increased to approximately 2.1 Volts to increase potential leakage current into sensing circuit 54 (FIG. 5). In an embodiment, current source 107 is provided for margin “1” testing.

Margin bias circuit 96 further includes PMOS transistors 110 and 112 sized to provide four (4) microamperes and five (5) microamperes of current, respectively. In an embodiment, transistors 108 and 109 are provided to turn off currents in transistors 110 and 112 after the data is latched in latch 92 (FIGS. 7a & 7b) to save power. In the illustrated embodiment, transistors 110 and 112 control the delivery of current via transistors 108 and 109, respectively. In an embodiment, transistors 110, 112, 108 and 109 provide current for normal read, transistor 110 and 108 provide current for margin “0” read, and transistors 110, 108, 112, 109, 104, 106 and current source 107 provide current for margin “1” read. It is emphasized that transistors 104, 106, 108, 109, 110, 112 merely provide an illustrative embodiment of one way to provide a bias current on bitline 26, and that the sizes of transistors 104, 106, 108, 109, 110, 112 are selectable based on the circumstances in which they are applied.

FIG. 10 is a block diagram of sensing circuit 54. Sense amplifiers 114 are connected to selected bitlines 26 through multiplexing provided by column multiplexors 52 and 52' (not shown in FIG. 10), i.e., one sense amp connected to each selected cell 10, 30 in line 24, 44, respectively. In an embodiment, twenty-two cells 10 or 30 in each line 24 or 44, respectively, results in twenty-two sense amplifiers 114 selected by column decode block 56 and multiplexors 52 and 52'. Lines 116 provide control signals and bias current for margin bias circuit 96 (FIGS. 7a & 7b) and pull-up circuit 98 (FIGS. 7a & 7b) to pre-charge each bitline 26, provide read operations and



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margin testing. In an embodiment, latch **92**, inverter **94**, margin bias circuit **96** and pull-up circuit **98** are components of sensing circuit **54**.

Under certain circumstances, transients on bitlines **26** may show up as noise on other bitlines **26**. Such noise may interfere with the ability of sense amplifier **114** to detect the data stored in a cell **10**, **30** selected for reading. Sense amplifiers may incorporate pre-discharge circuitry to address such an issue. Upon a particular cell **10**, **30** having been selected to be read, bitlines **26** not corresponding to the particular cell **10**, **30** to be read may be driven to a predetermined state. In an embodiment, circuitry of sensing circuit **54** and column multiplexors **52** and **52'** provide pre-discharge of unselected bitlines **26**. Pre-discharge circuits of sense amplifiers **114** and multiplexors **52** and **52'** may be configured to drive bitlines **26** not related to the particular cell **10**, **30** to be read to ground before reading the selected cell **10**, **30**. In so doing, transients on the bitlines **26** not corresponding to the selected cell **10**, **30** may be avoided and, as a result, noise on the bitline **26** of the selected cell **10**, **30** may be reduced.

FIG. **11** is a flowchart for providing a memory array such as memory module **50**. A plurality of flash memory cells **10** and ROM memory cells **30** are provided (**1100**) on memory module **50**. In an embodiment, flash memory cells **10** and ROM memory cells **30** are fabricated on one or more silicon dies as known in the art. In an embodiment, at least some of flash memory cells **10** and at least some ROM memory cells **30** are fabricated on the same silicon die. Addressing circuitry, including at least column decode block **56** and row decoder **70**, are provided (**1102**). In an embodiment, at least some of the addressing circuitry is provided on the same silicon die as the at least some flash memory cells **10** and ROM memory cells **30**.

FIG. **12** is a flowchart for using a memory array such as memory module **50**. Addressing circuitry as described above is utilized to address (**1200**) both flash memory cells **10** and ROM memory cells **30**. Reading circuitry, including at least sensing circuit **54**, reads (**1202**) both flash memory cells **10** and ROM memory cells **30**.

FIG. **13a** is a flowchart for operating a memory module such as memory module **50**. Individual data bits such as memory cells **10**, **30** are selectively coupled (**1300**) to a voltage sensing circuit such as sensing circuits **54**. Individual ones of the data bits are selectively biased (**1302**) by at least margin bias circuit **96** and pull-up circuit **98**. The data state of the data bit is read (**1304**) based, at least in part, on a voltage of or imparted by the individual one of the plurality of data bits. If the reading (**1304**) is a margin test, it is determined (**1306**) whether the voltage corresponds to a correct data state. The margin test may be a margin high test, i.e., a margin "1" test, or a margin low test, i.e., a margin "0" test as detailed above. Margin bias circuit **96** is utilized to selectively bias (**1308**) the selected data bit. Bitline **26** not corresponding to the data bit may be pre-discharged (**1310**) prior to reading (**1304**) the data bit and, in an embodiment, each bitline **26** not corresponding to the data bit is pre-discharged prior to reading (**1304**) the data bit.

FIG. **13b** is an alternative flowchart utilizing essentially the same steps as illustrated in FIG. **13a** but which specifies a particular order for the steps of FIG. **13a**, as well as the additional step of pre-charging (**1312**) selected bitlines **26**.

Thus, embodiments of the memory array with flash memory cells and ROM memory cells and methods are disclosed. One skilled in the art will appreciate that the present invention can be practiced with embodiments other than those disclosed. The disclosed embodiments are presented for purposes of illustration and not limitation, and the present invention is limited only by the claims that follow.

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What is claimed is:

1. A memory array configured to store a plurality of data bits, comprising:

a plurality of flash memory cells;  
a plurality of ROM memory cells; and

addressing circuitry operatively coupled to both said plurality of flash memory cells and said plurality of ROM memory cells, said addressing circuitry being configured to address both said plurality of flash memory cells and said plurality of ROM memory cells;

wherein said plurality of data are arranged in bitlines; wherein said plurality of flash memory cells have a flash bitline address spacing, wherein said plurality of ROM memory cells have a ROM bitline address spacing, and wherein said flash bitline address spacing of said plurality of flash memory cells are approximately equal to said ROM bitline address spacing of said plurality of ROM memory cells.

2. The memory array as in claim 1 further comprising read circuitry operatively coupled to both said plurality of flash memory cells and said plurality of ROM memory cells, said read circuitry being configured to read both said plurality of flash memory cells and said plurality of ROM memory cells.

3. The memory array as in claim 2 wherein said memory array is comprised of a single memory array and wherein said single memory array comprises both said plurality of flash memory cells and said plurality of ROM memory cells.

4. The memory array as in claim 3 wherein said memory array further comprises overhead circuitry including at least one of a power source, a voltage generator and an addressing block, said overhead circuitry being shared by both said plurality of flash memory cells and said plurality of ROM memory cells.

5. A method of providing a memory array configured to store a plurality of data bits, comprising the steps of:

providing, in a single array, a plurality of flash memory cells and a plurality of ROM memory cells; and

providing addressing circuitry, operatively coupled to both said plurality of flash memory cells and said plurality of ROM memory cells, configured to address both said plurality of flash memory cells and said plurality of ROM memory cells;

wherein said plurality of data are arranged in bitlines; wherein said plurality of flash memory cells have a flash bitline address spacing, wherein said plurality of ROM memory cells have a ROM bitline address spacing, and wherein said flash bitline address spacing of said plurality of flash memory cells are approximately equal to said ROM bitline address spacing of said plurality of ROM memory cells.

6. The method as in claim 5 further comprising the step of providing read circuitry, operatively coupled to both said plurality of flash memory cells and said plurality of ROM memory cells, said read circuitry being configured to read both said plurality of flash memory cells and said plurality of ROM memory cells.

7. The method as in claim 6 further comprising the step of providing overhead circuitry including at least one of a power source, a voltage generator and an addressing block, said overhead circuitry being shared by both said plurality of flash memory cells and said plurality of ROM memory cells.

8. A method of using a memory array configured to store a plurality of data bits having, in a single array, a plurality of flash memory cells and a plurality of ROM memory cells, comprising the steps of:

addressing both said plurality of flash memory cells and said plurality of ROM memory cells with addressing circuitry common to both said plurality of flash memory cells and said plurality of ROM memory cells; and

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reading both said plurality of flash memory cells and said plurality of ROM memory cells with reading circuitry common to both said plurality of flash memory cells and said plurality of ROM memory cells;

wherein said plurality of data are arranged in bitlines; 5  
wherein said plurality of flash memory cells have a flash bitline address spacing, wherein said plurality of ROM memory cells have a ROM bitline address spacing, and wherein said flash bitline address spacing of said plurality of flash memory cells are approximately equal to said 10  
ROM bitline address spacing of said plurality of ROM memory cells.

9. The method as in claim 8 wherein said memory array has overhead circuitry including at least one of a power source, a voltage generator and an addressing block, said overhead 15  
circuitry being shared by both said plurality of flash memory cells and said plurality of ROM memory cells.

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